ASME 2010 First Global Congress on
NanoEngineering for Medicine and Biology (NEMB2010)

Development of Micro-Spectrometer for Neural Probe with Wireless Power Feed

Uhn Lee
Gacheon University of Medicine and Science, Incheon, Korea

Sang H. Choi
NASA Langley Research Center, Hampton, VA

Kyo D. Song
Norfolk State University, Norfolk, VA

Yeonjoon Park
National Institute of Aerospace, Hampton, VA

NASA SAA #15546 Collaboration Activity

Deep Brain Stimulation (DBS) and its Limits

Performance:

Jolt suppression voltage only

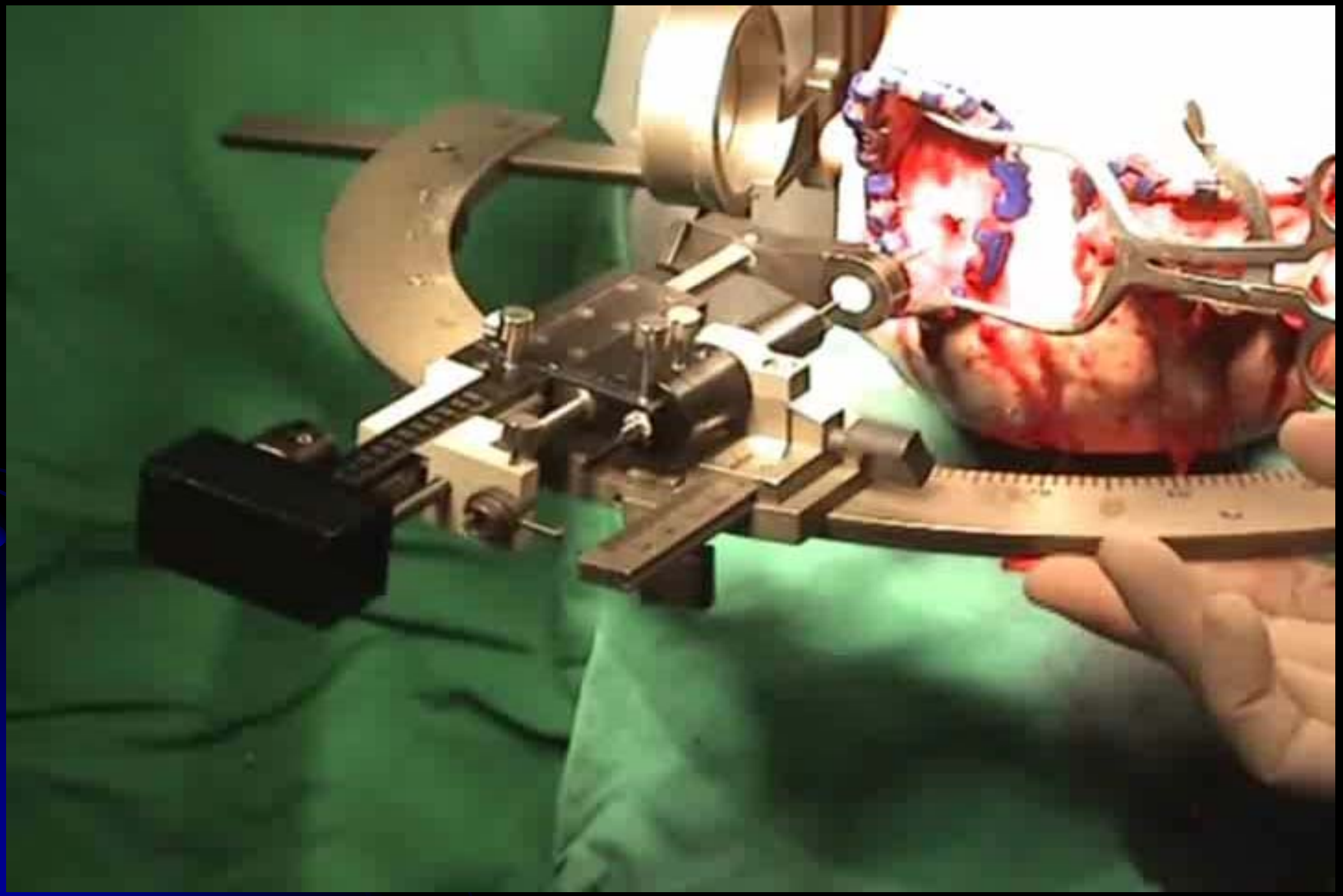
- diagnosis and search of anomaly required
- a single function

Power Source:

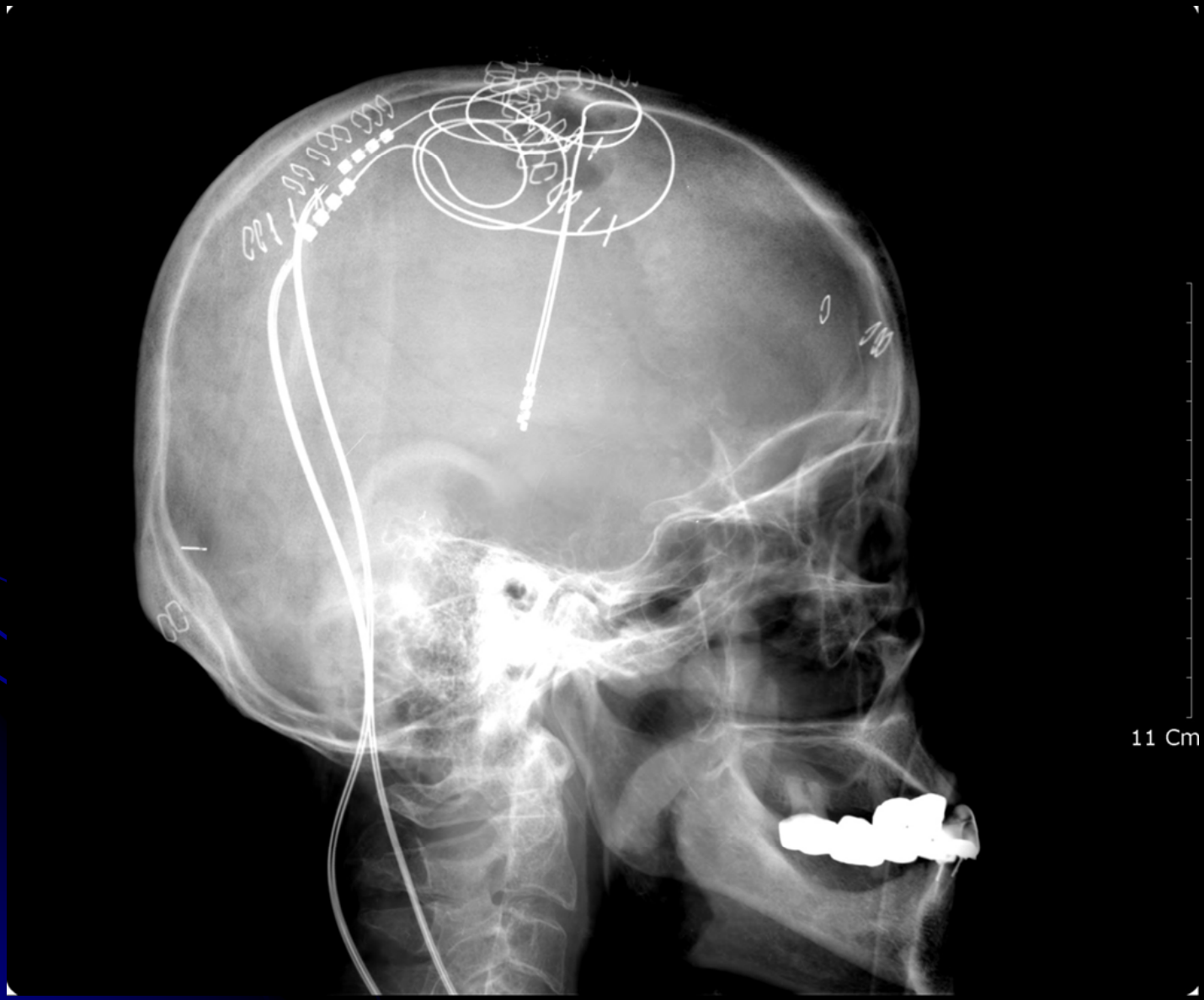
Implanted battery with tether line

- painful and cumbersome
- battery lasts 3~5 years
- power-line vulnerable to disconnection

DBS Implantation



Implanted DBS



New Approach: Probe-Pin Device

Performance:

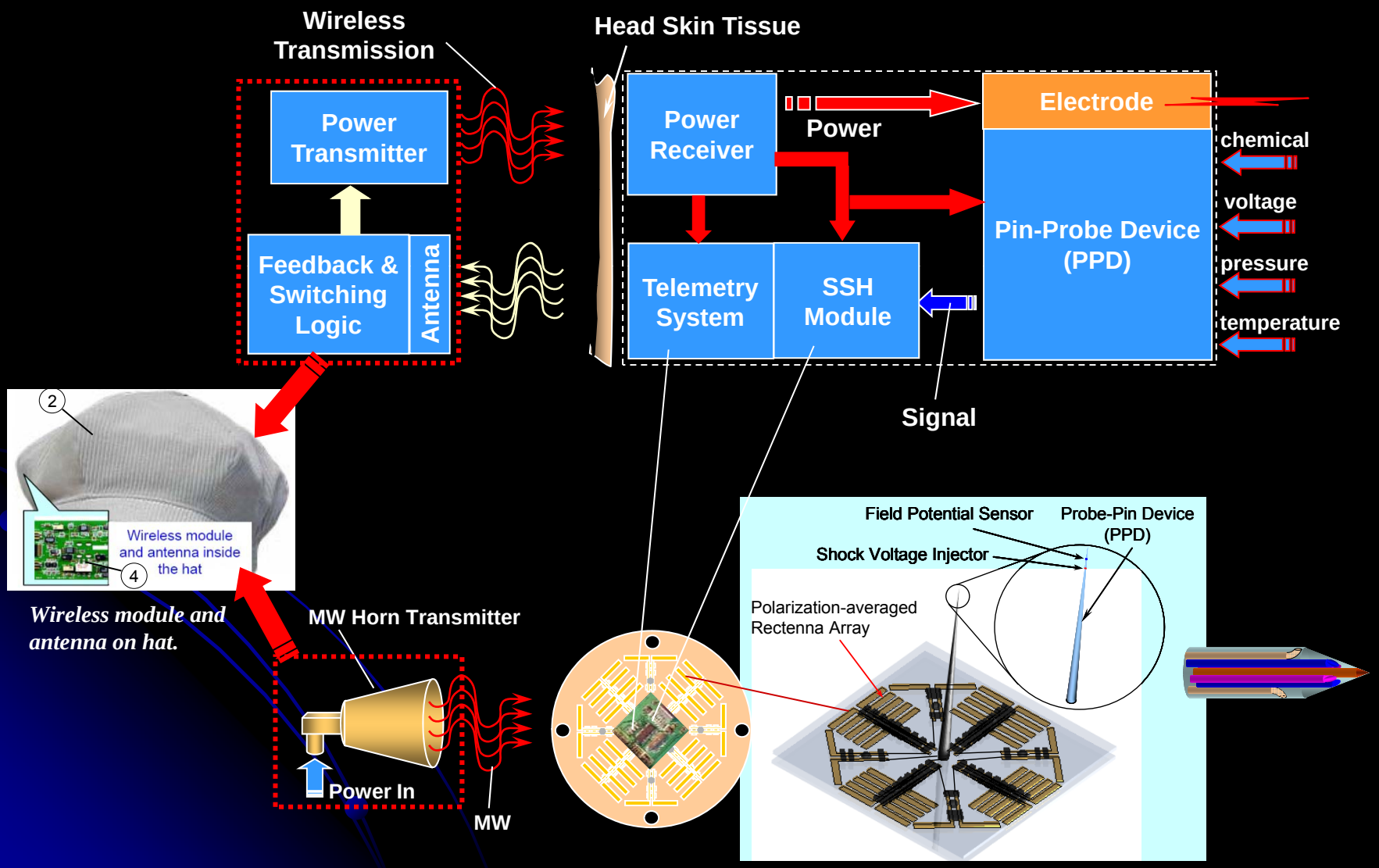
- Diagnosis and search of anomaly required
- Multi-functions integrated
  - Jolt suppression voltage
  - Neuro-chemistry by micro-spectrometer
  - Neuro-electricity
  - Brain temperature
  - Brain pressure

Power Source:

- Wirelessly powered thru human tissue
  - Micro-coil with train of magnetic pulses
  - Rectenna array for microwave coupling

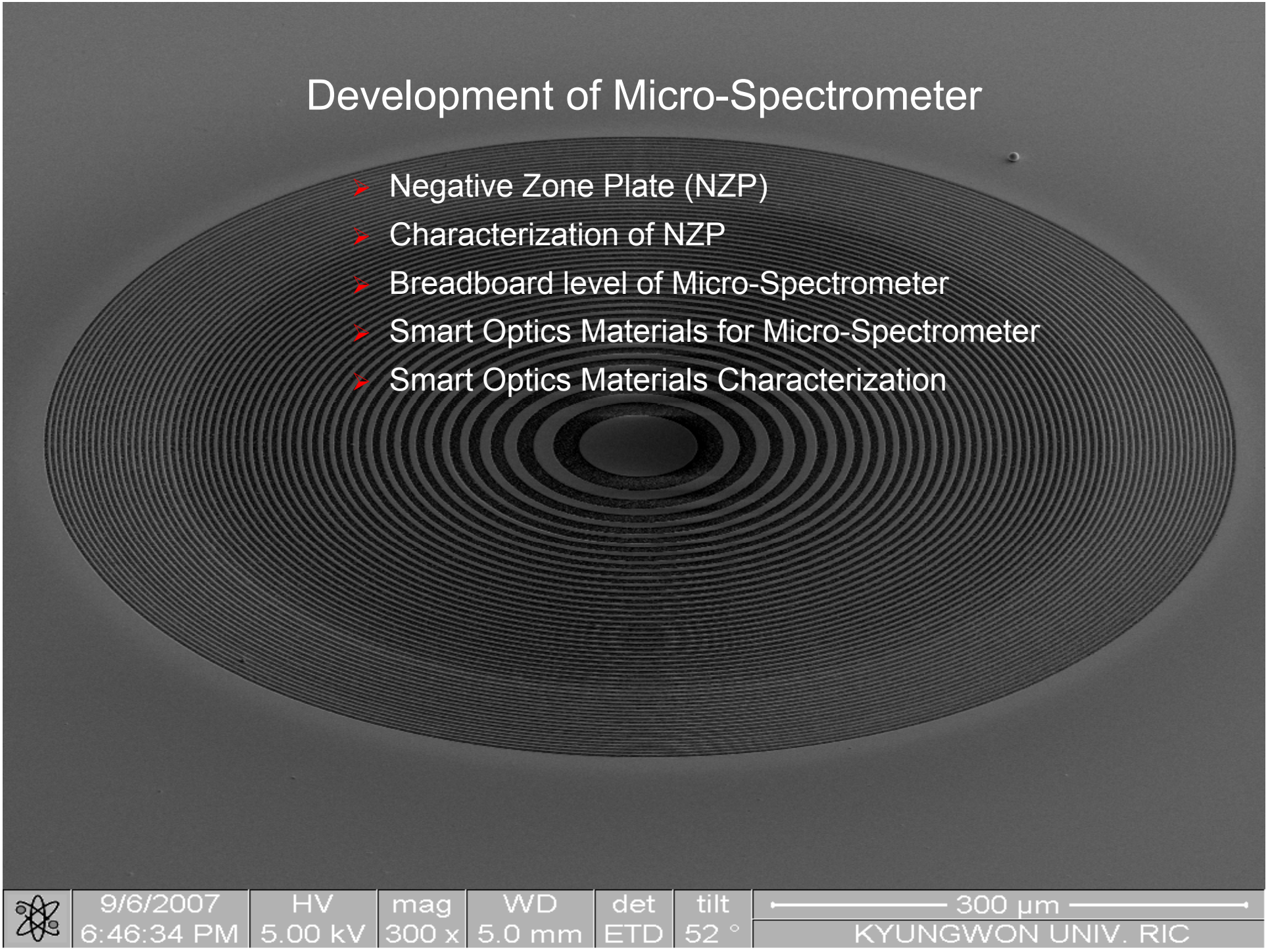
Logic Circuit for Monitoring, Control, and Data Acquisition

Master Logic dependent PPD



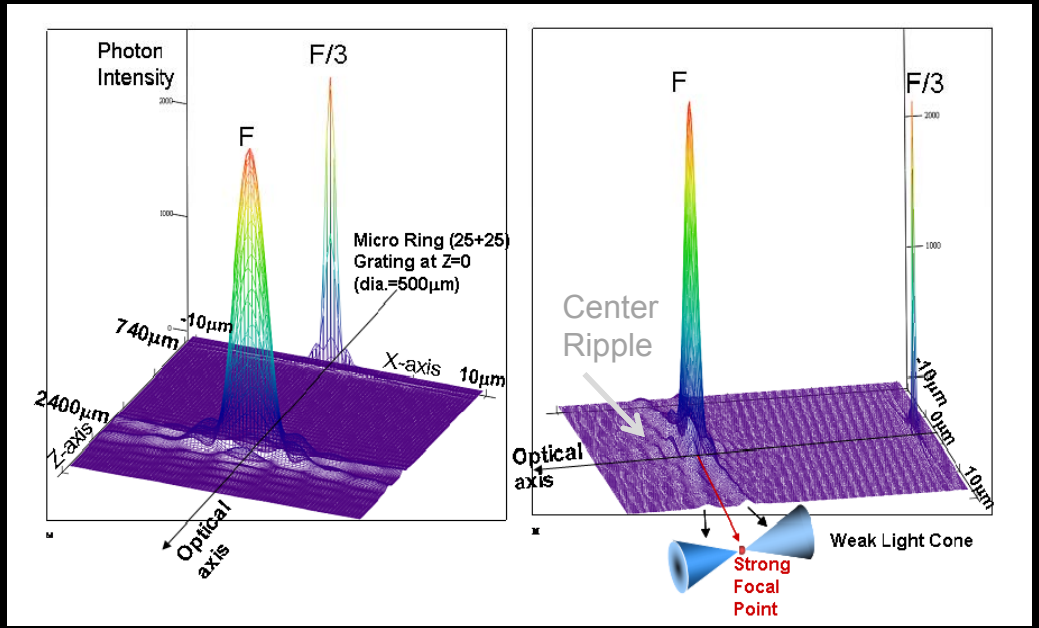
Development of Micro-Spectrometer

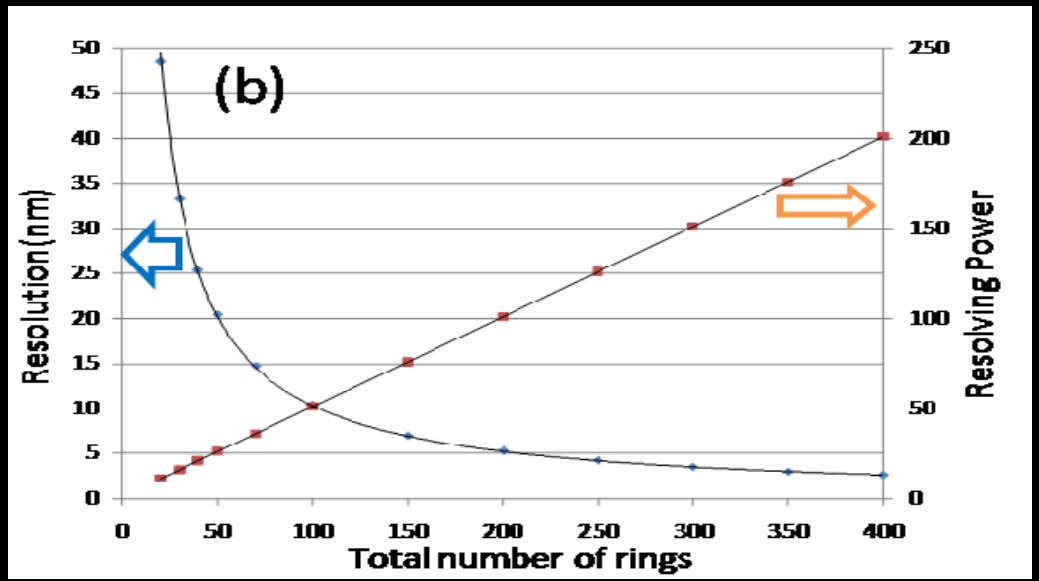
- Negative Zone Plate (NZP)
- Characterization of NZP
- Breadboard level of Micro-Spectrometer
- Smart Optics Materials for Micro-Spectrometer
- Smart Optics Materials Characterization



Photon Intensity Simulation for Micro Ring Grating Spectrometer

- 3-D optical simulation for 500 μm ring grating (25 transparent rings) with Fresnel diffraction.
- Photon intensity map of optical axis (z-axis) vs. radius direction (x-axis) shows strong focusing effect and spectral separation.
- Spectral resolution ($\Delta\lambda$) is improved with the increasing number (n) of rings as 1/n.
  - $\Delta\lambda$=20 nm for 50 rings
  - $\Delta\lambda$=10 nm for 100 rings
- Each wavelength has a strong focal point which is surrounded by two weak light cones.
- Circular aperture slit of 1% of the ring grating diameter will pass the photons of a selected wavelength.

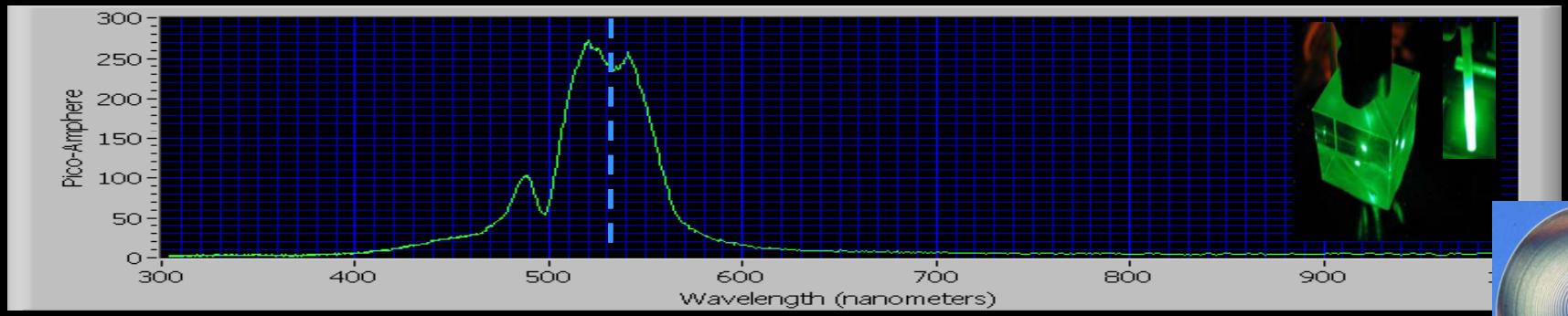


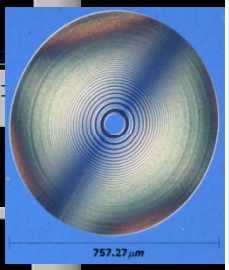


Spectral scans:

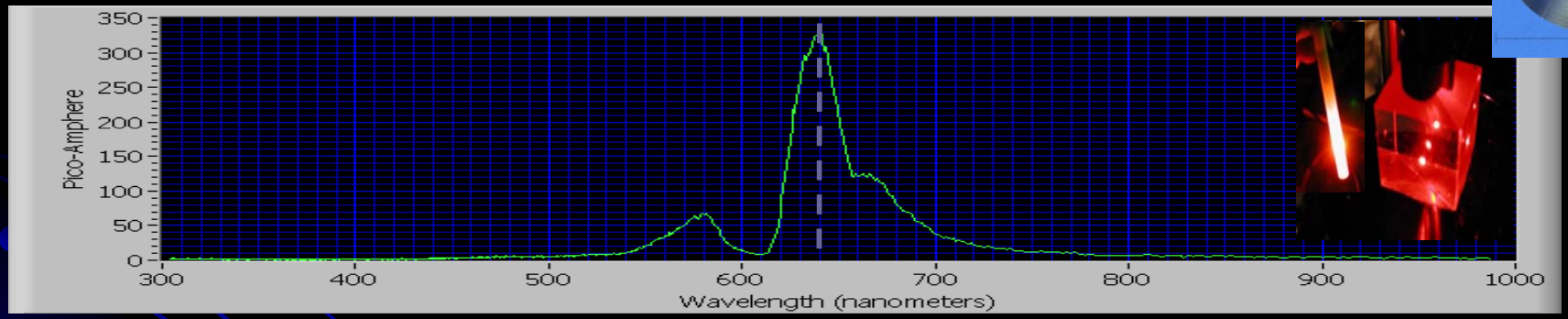
Circular Grating: 100 rings, 757μm diameter
Aperture: 10 μm diameter

Green Laser: 532nm

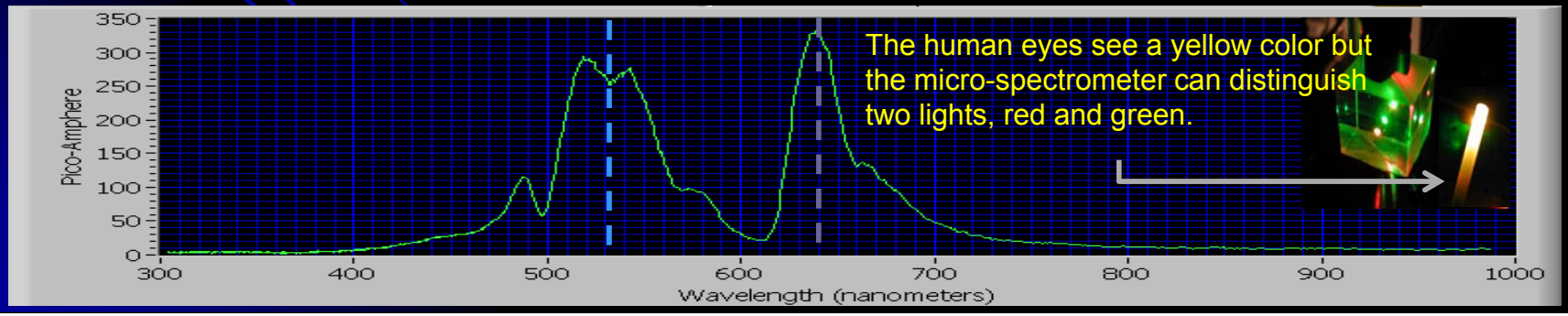




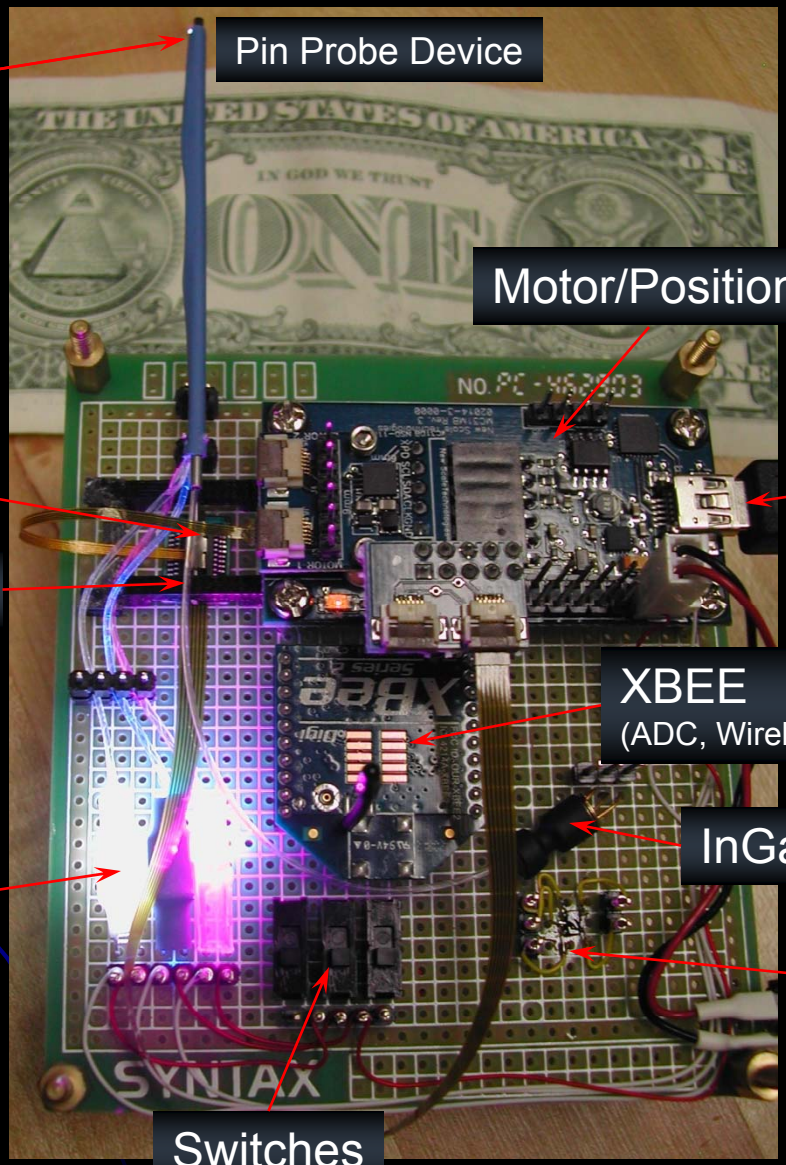
Red Laser: 633nm



Green & Red Lasers: 532nm & 633nm



Micro-Spectrometer
Component Test Platform



Configuration Diagram

Light Sources: White, Blue, UV LED

Photon Injection via Light Pipe

Illumination on Object (Inside Body)

Light Collection via Fresnel Grating

Movable aperture slit with linear motor
(to be replaced by SOM)

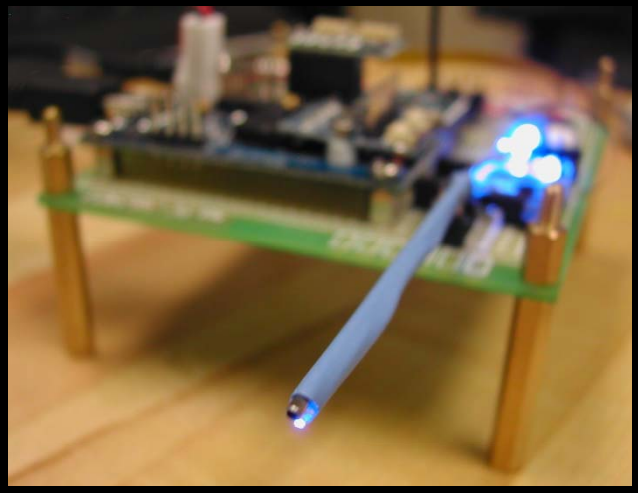
InGaAs Photon Detector

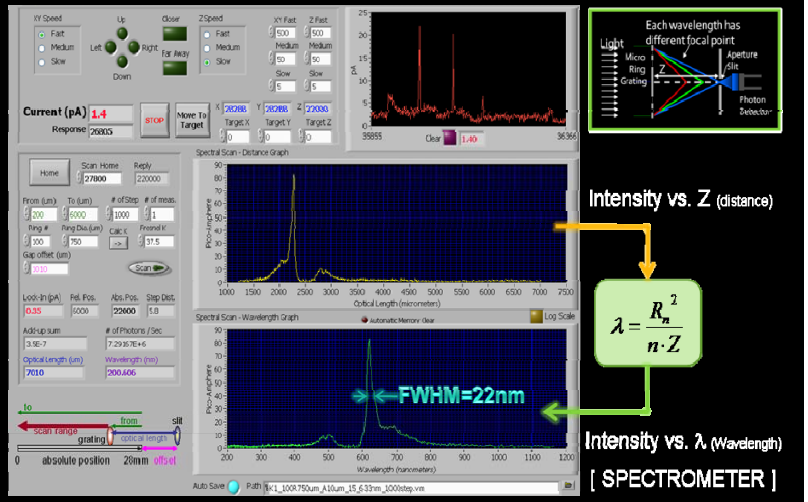
Current to Voltage Conversion
with Micro OP-Amplifier

Analog to digital conversion with XBEE

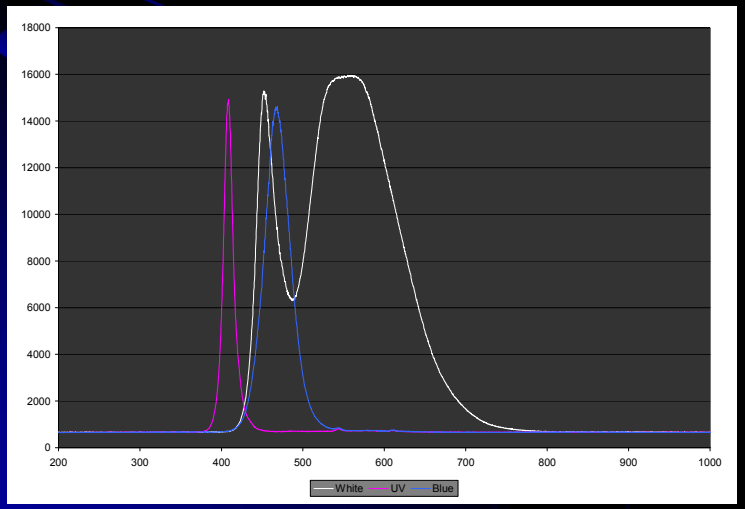
Wireless data transfer with XBEE

Computer



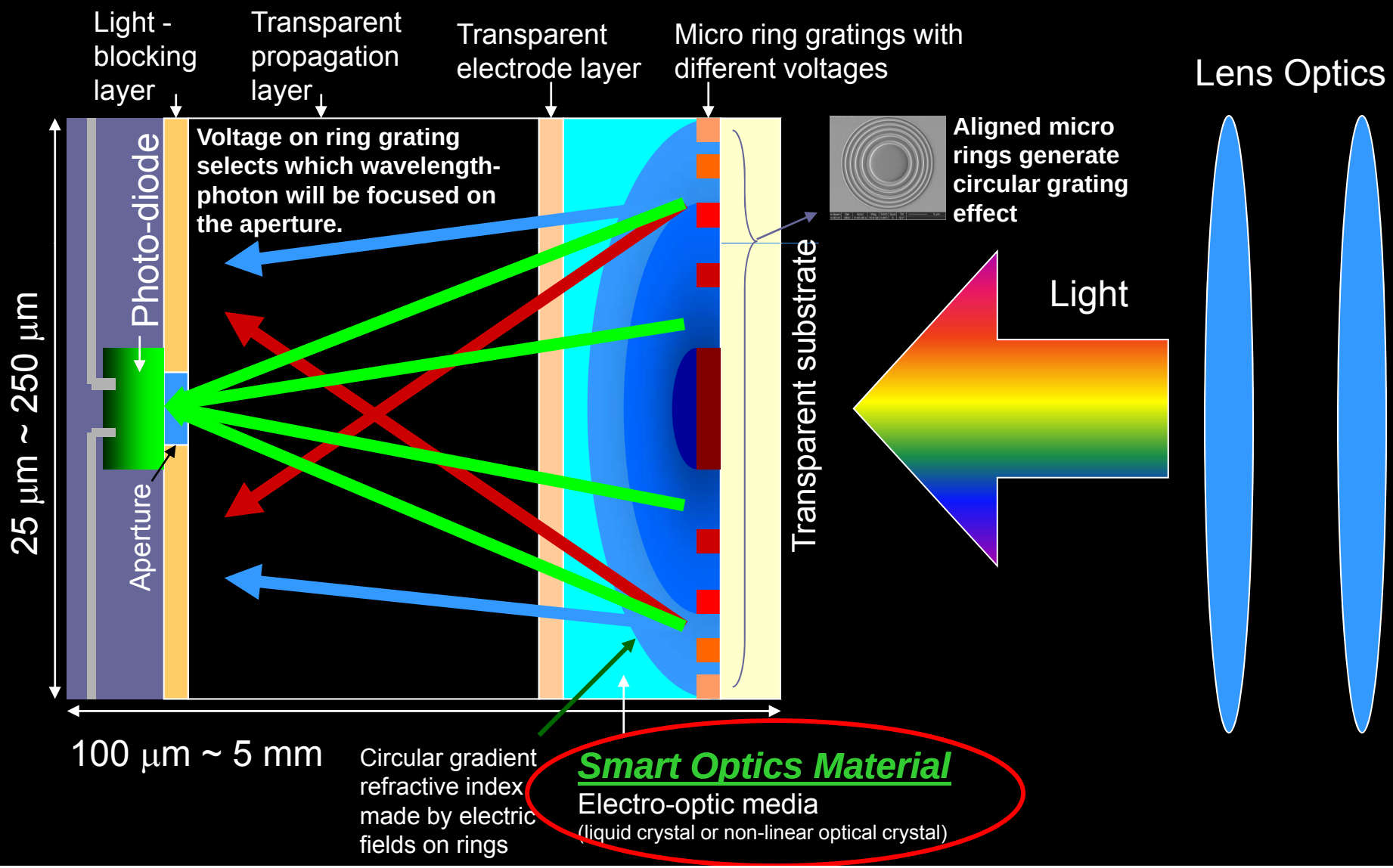


Micro-Spectrometer Component Test Platform Parameters



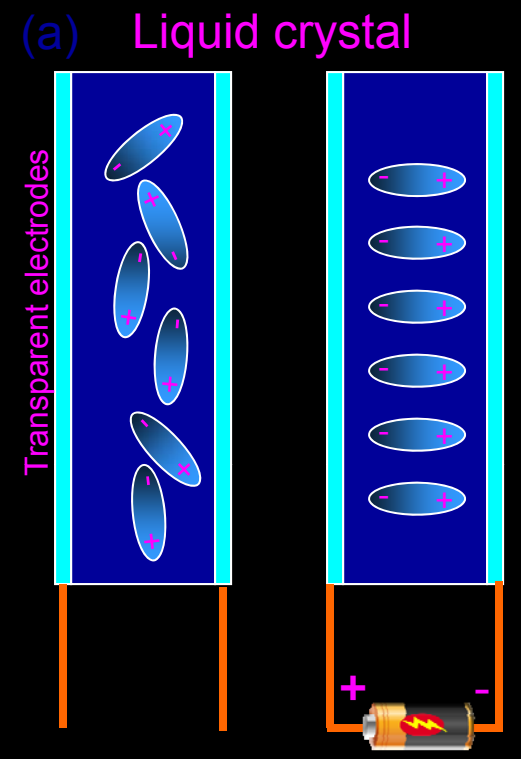
- Light Sources: White, Blue, and UV LED
- Integrated Light Pipe Design: Diameter = 3mm
- Micro Linear Motor: Travel Distance = 6mm
- Magnetic Micro-Position Sensor: 2 micrometer resolution
- Photo Detector: InGaAs Photo Diode
- Mini OP-Amplifier: Gain (V/I) = 10^7
- USB/Serial Interface to control linear motor
- Power: 3.3V, 1.8A max
- ADC & Wireless Data Transfer: XBEE Chipset (ZigBee Network)

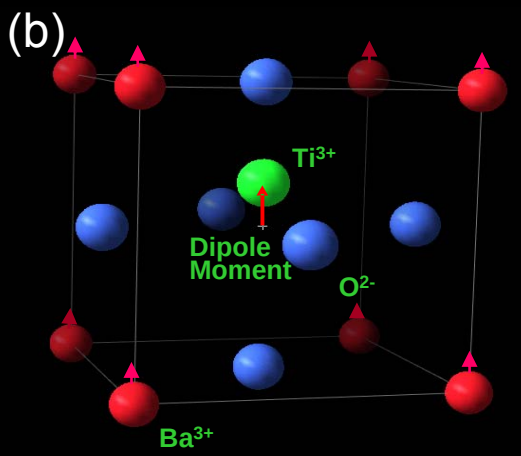
μ-Spectrometer Development Plan



Smart Optics Materials

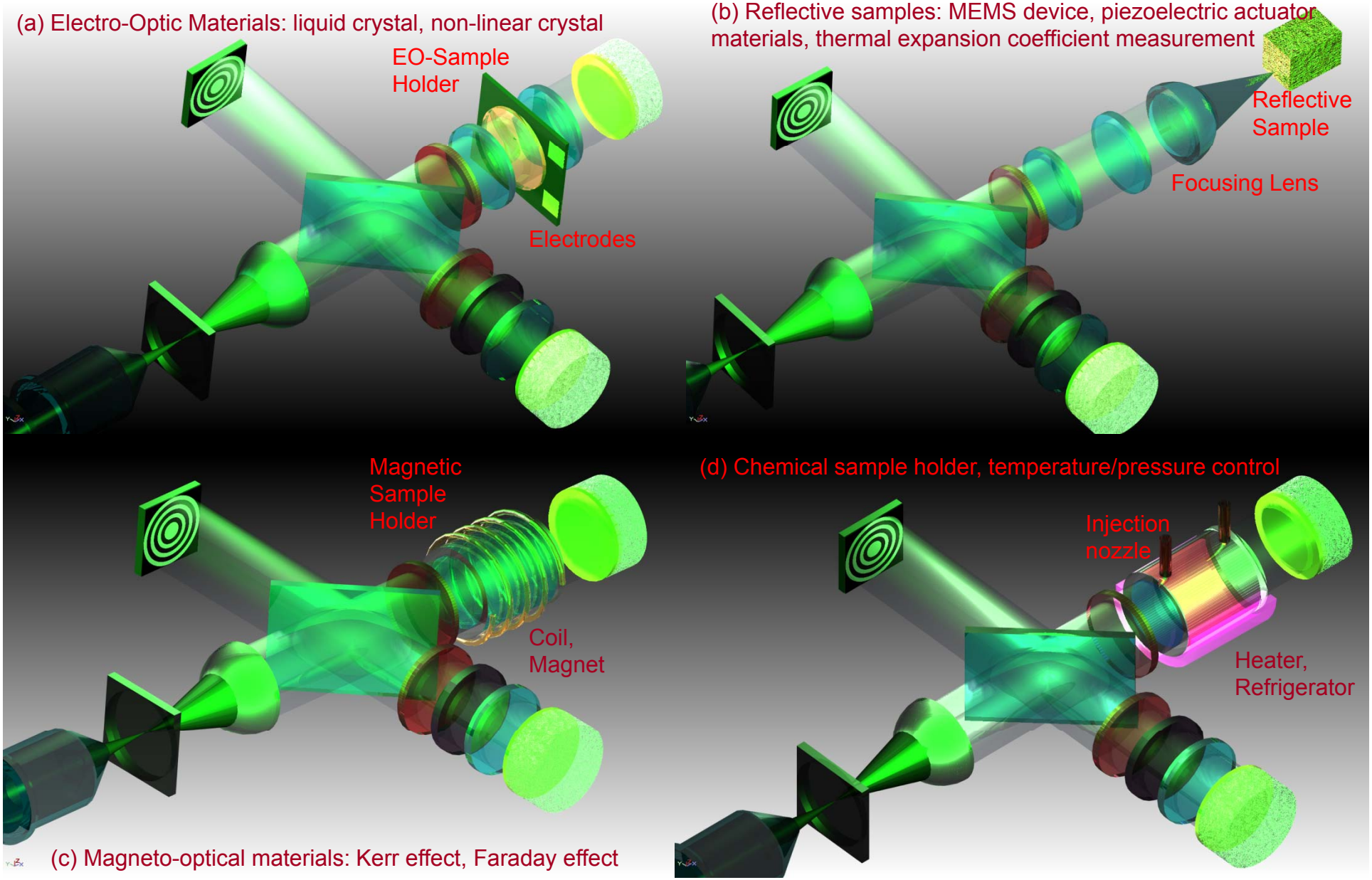
- Smart Optics Materials (SOM) are new optical materials that can control deep properties (intensity, phase, polarization, coherence) of passing light, including
  - electro-optic materials (non-linear optical crystals, liquid crystals, electro-optic polymers)
  - magneto-optic materials (Faraday Effect and Kerr Effect),
  - electro/thermo-chromic materials
  - chemicals that induce refractive index changes
  - optical materials that depend on temperature and pressure
- New prototype SOM characterization system with advanced software is under development at NASA LaRC.
  - Intensity, phase, and polarization of passing lights through many new optical materials while applying various physical/chemical quantities on the materials.
  - A miniaturized compact system has USB interface and exchangeable components for various R&D and commercial applications.
  - This innovative versatile SOM characterization system and characterized optical materials will be used for complete micro spectrometer system.
  - Commercialization of this system accelerates development of new optical materials and devices.



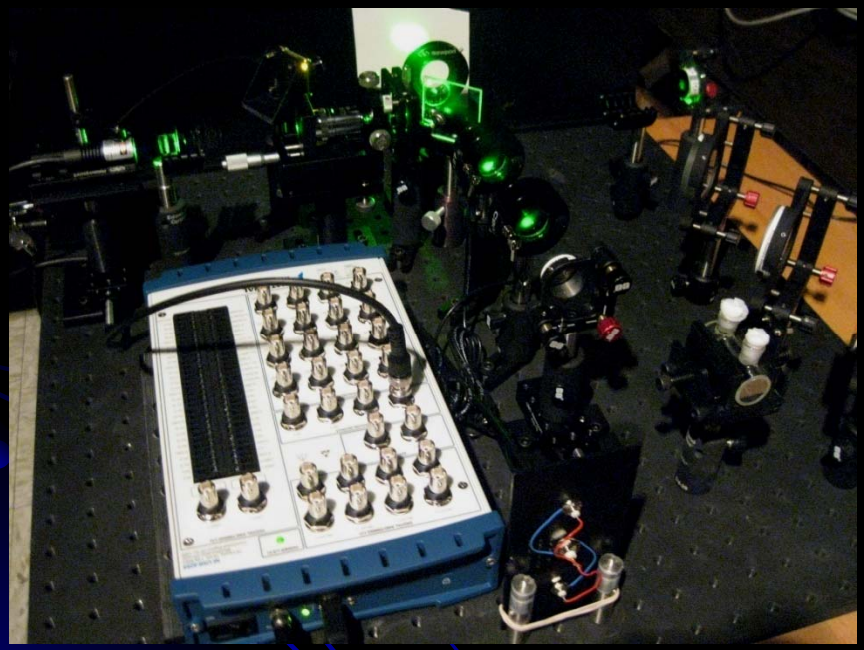


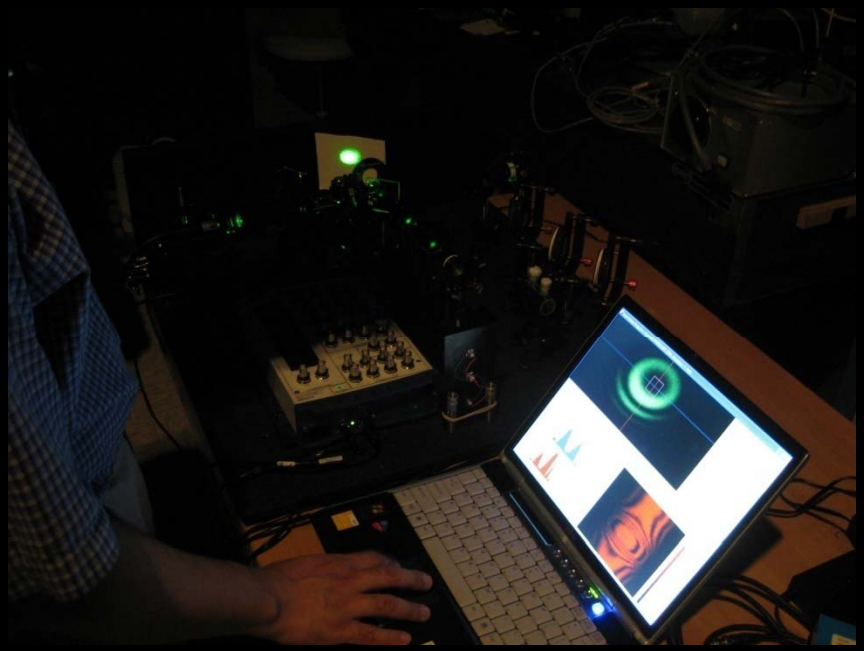
Non-linear optical crystal

Smart Optics Material Characterization System

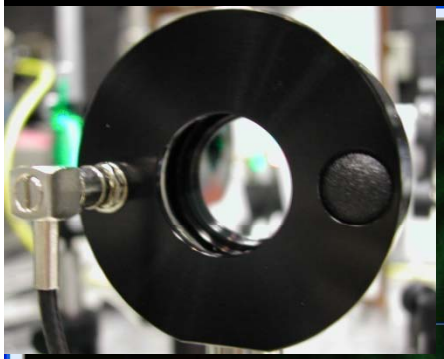


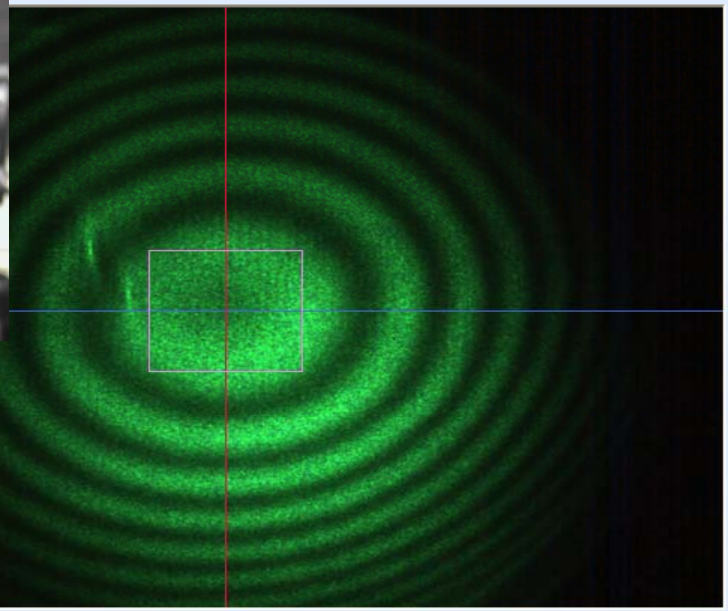
Smart Optics Material Characterization System

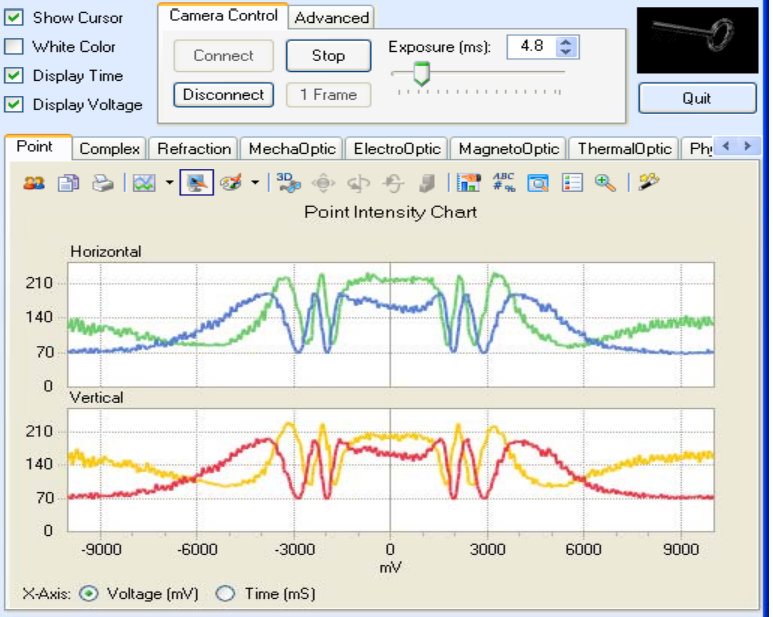


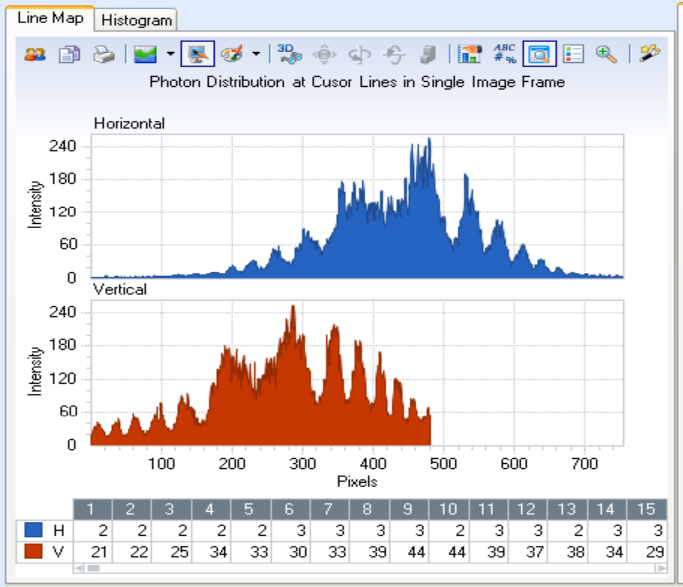


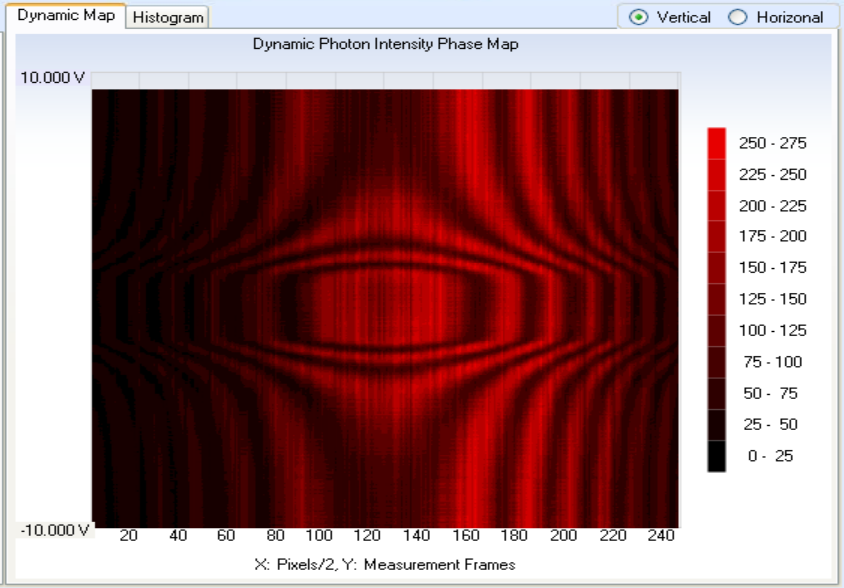
SOM Characterizer Software

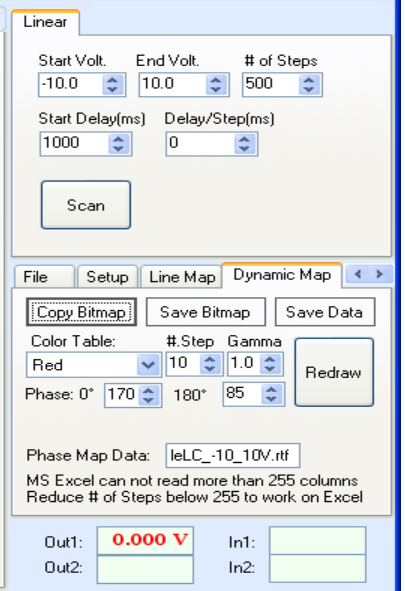






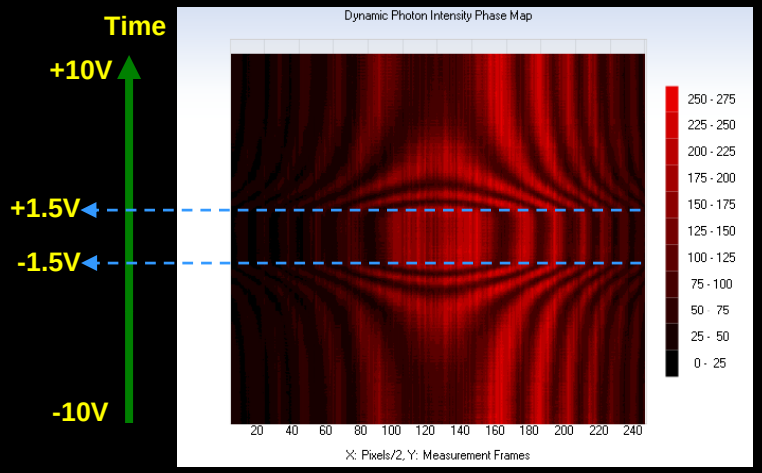


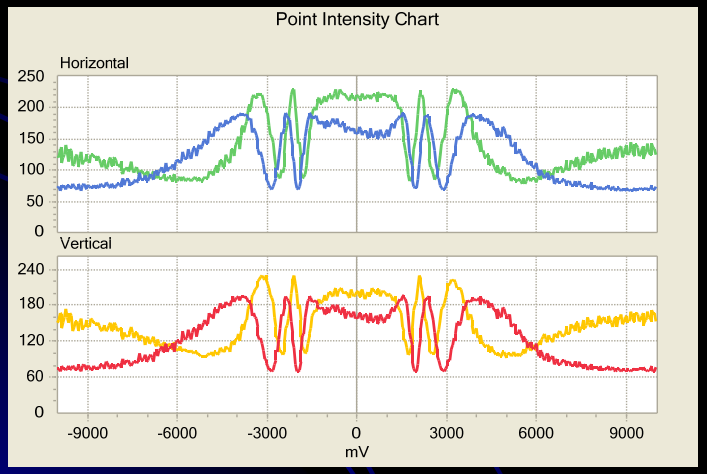




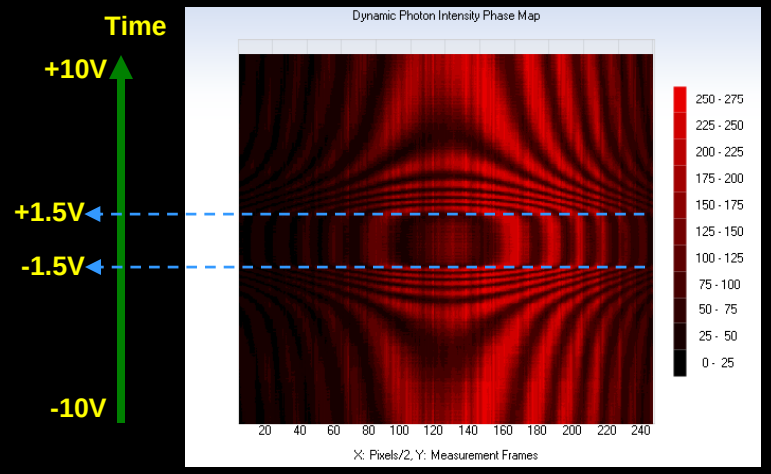
Progress: | Cursor (418,241) | Offset (469,289) [51,48] | Mouse (693,26) | Ready

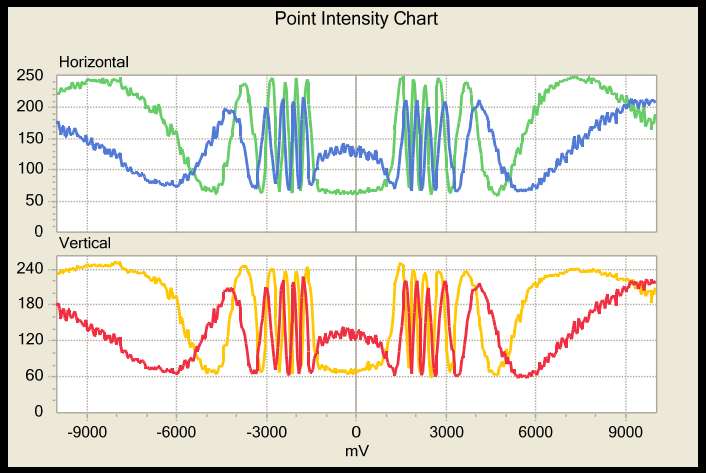
Dynamic Phase Map Analysis





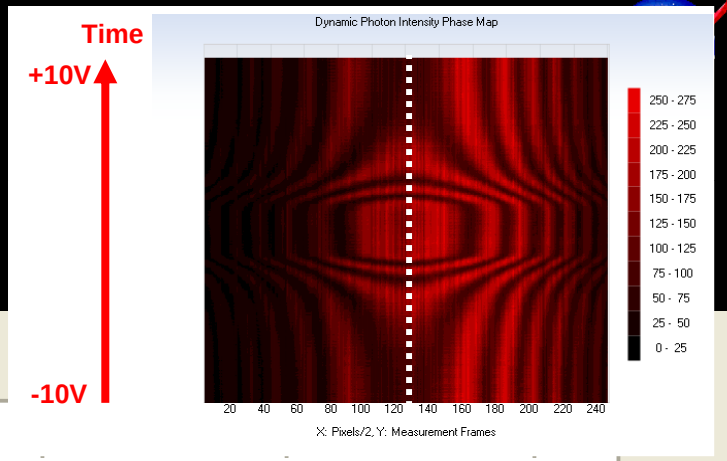
Liquid Crystal Single Layer

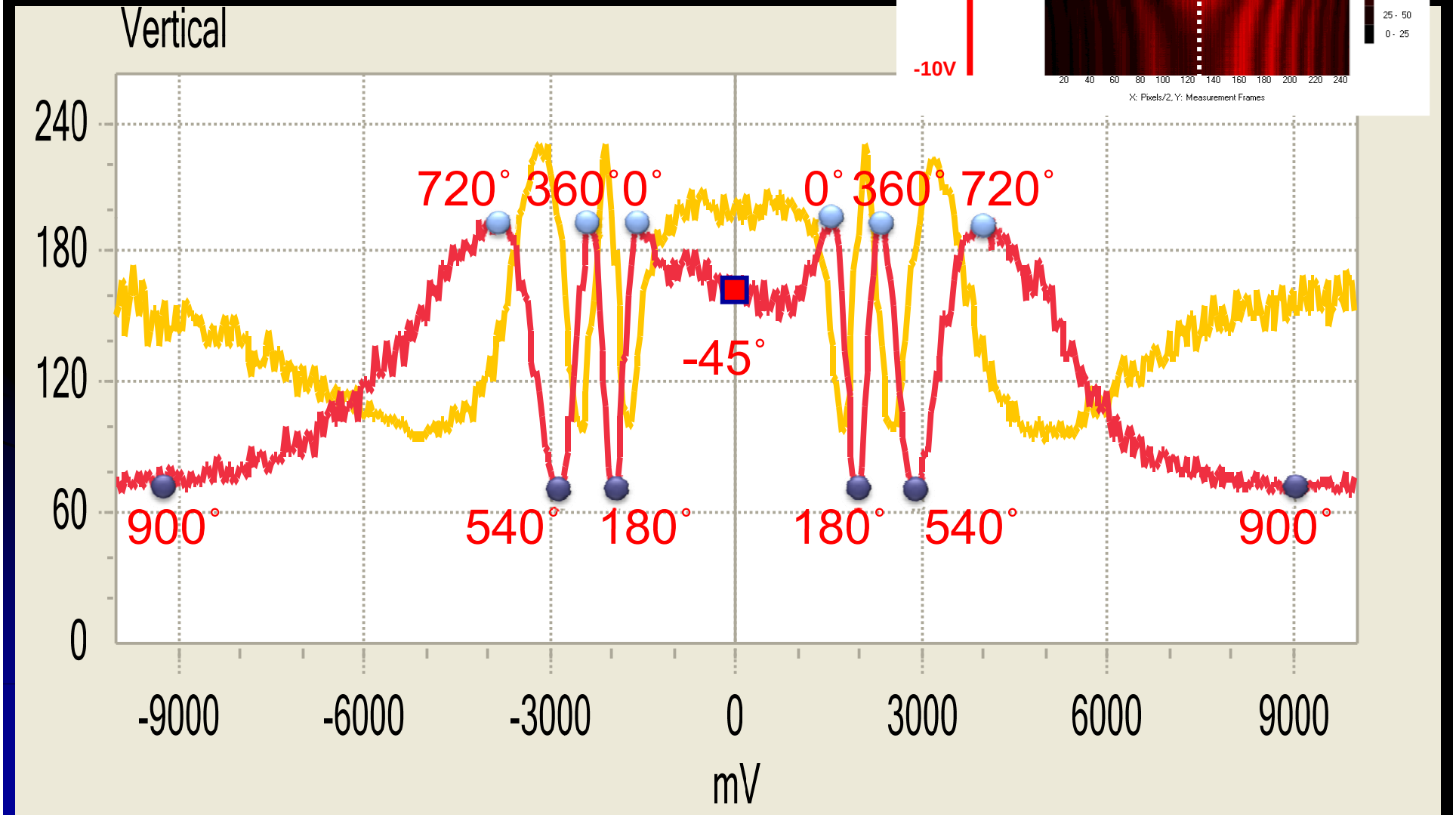




Liquid Crystal Double Layer

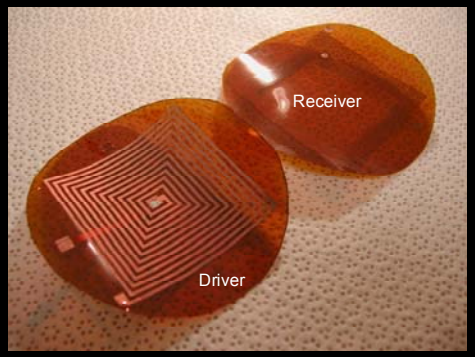
Phase Angle Measurement





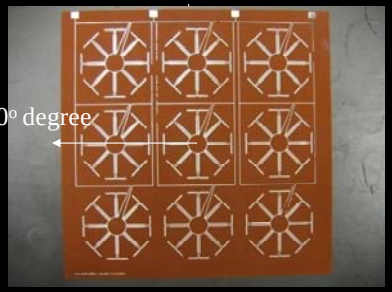
Mobile Wireless Power Transfer with Micro Coil and Microwave

Micro Induction Coil (MIC)

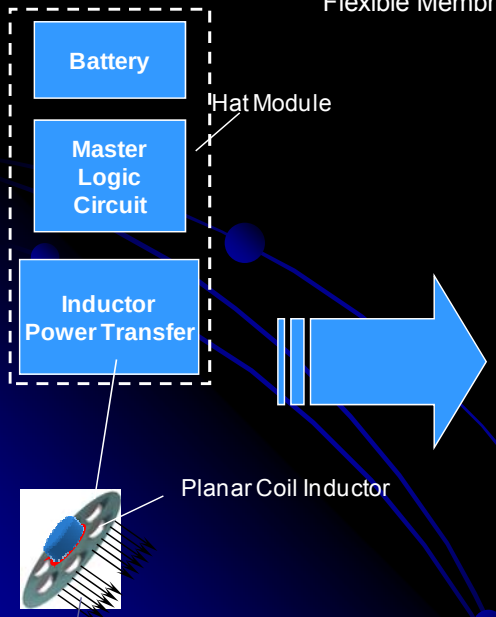


Flexible Membrane Inductor

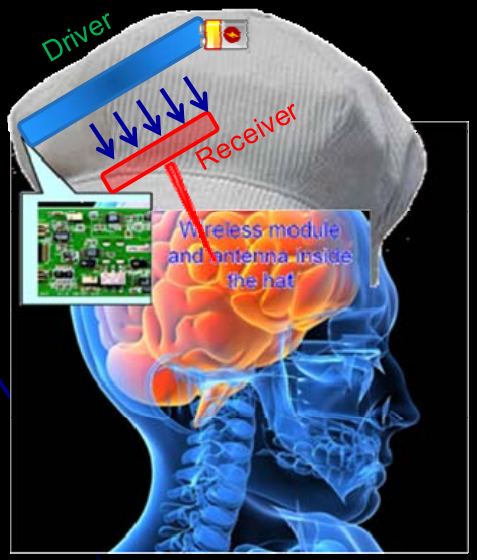
Thin-Film Rectenna Array (TFRA)

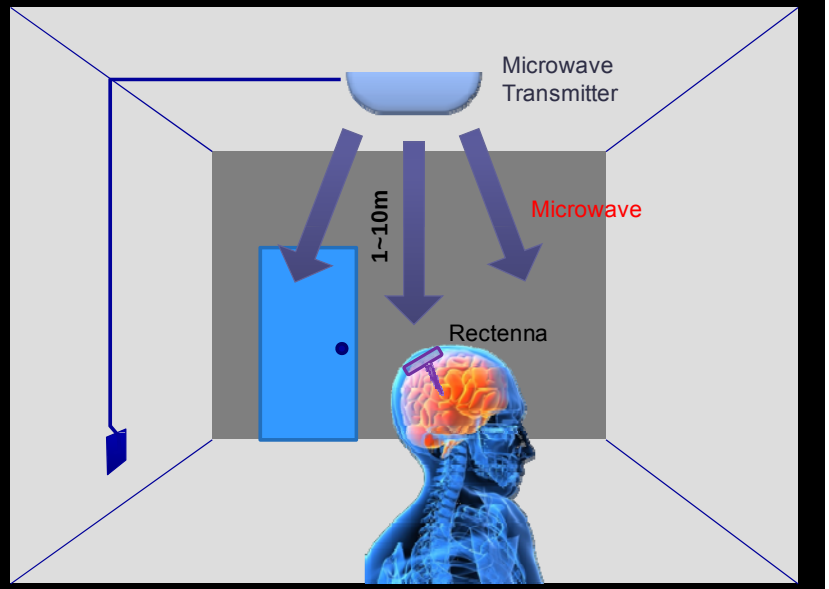


3 x 3 flexible rectenna



Short Range (1~10cm) Solution

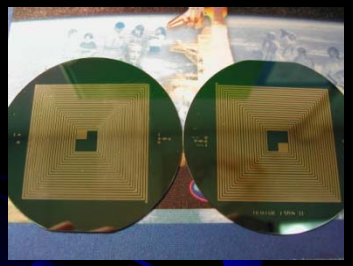




Wireless Power Transfer

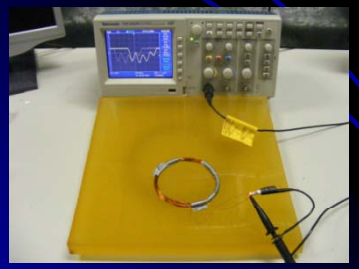
Inductance Power Transfer

- 0-3 cm, short range
- Safe for human interaction
- low power applications

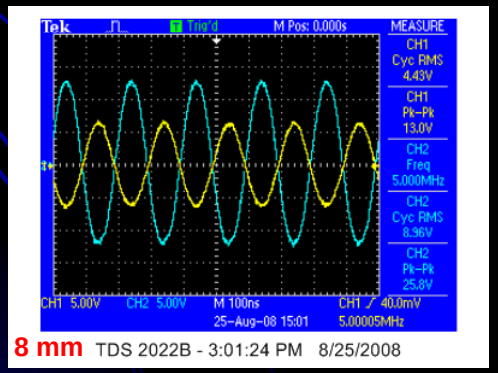


Planar Coils

Coil powering an LED



Coil Test Setup



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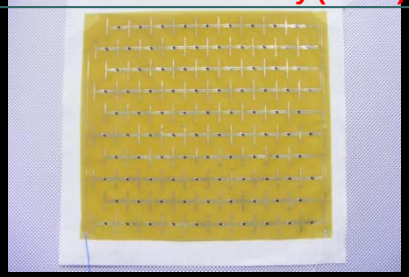
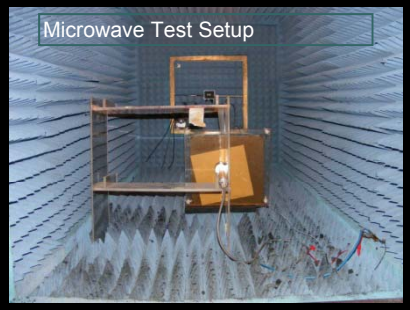
Microwave Power Transfer

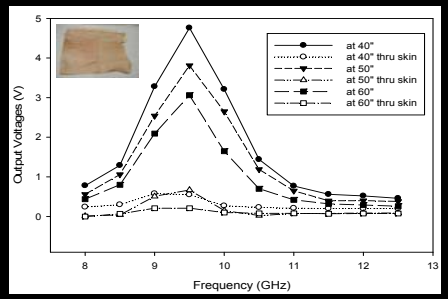
- 1-1000 m, long range
- Low to high power applications

Thin-Film Rectenna Array (TFRA)

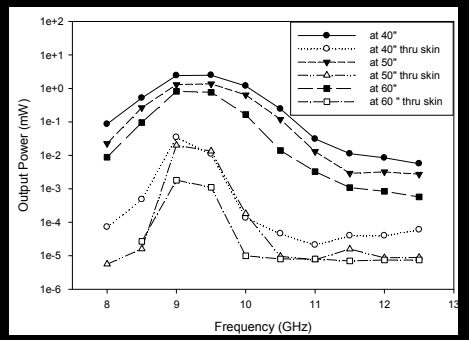




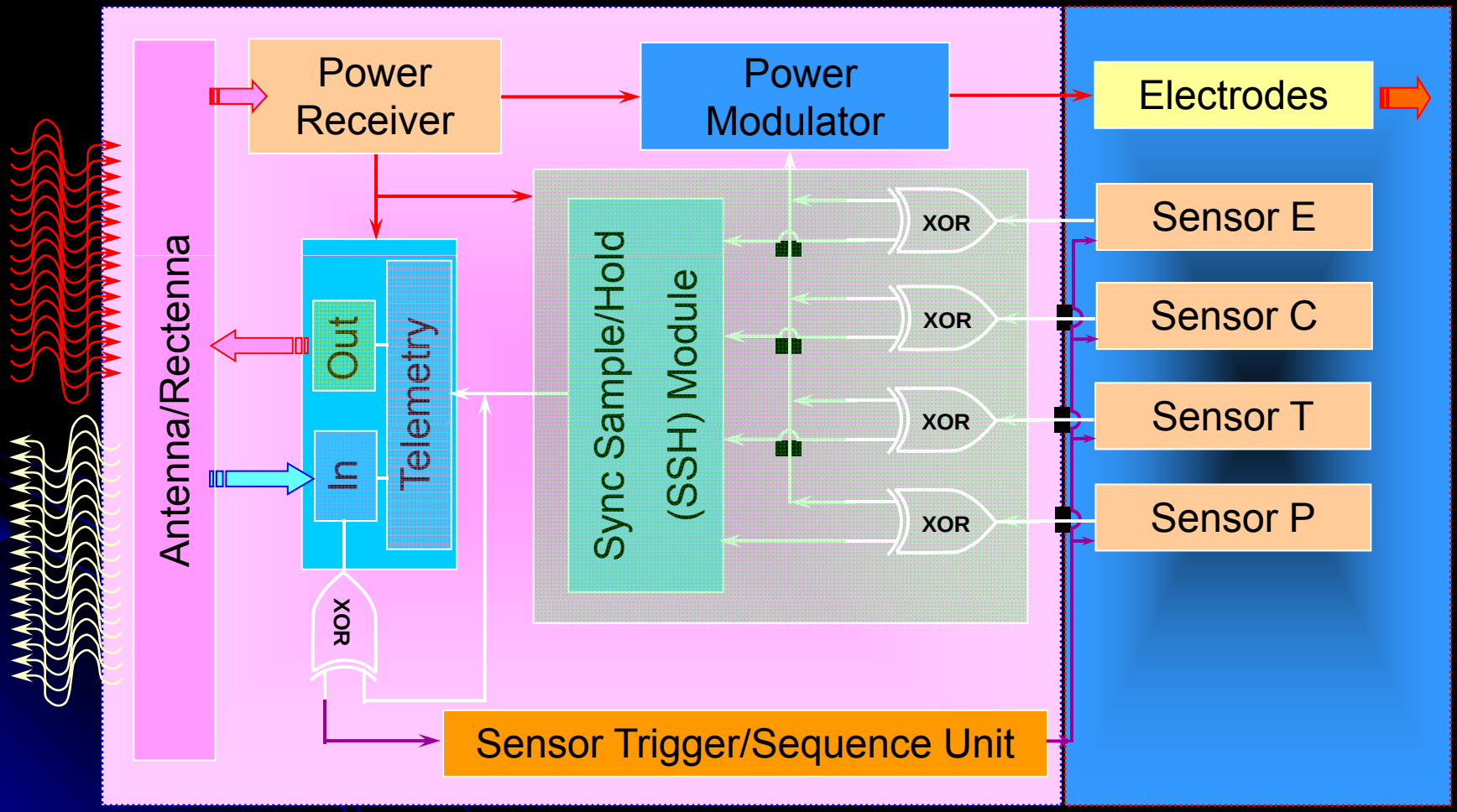
Flexible Rectenna Array



Microwave Generator and Amplifier

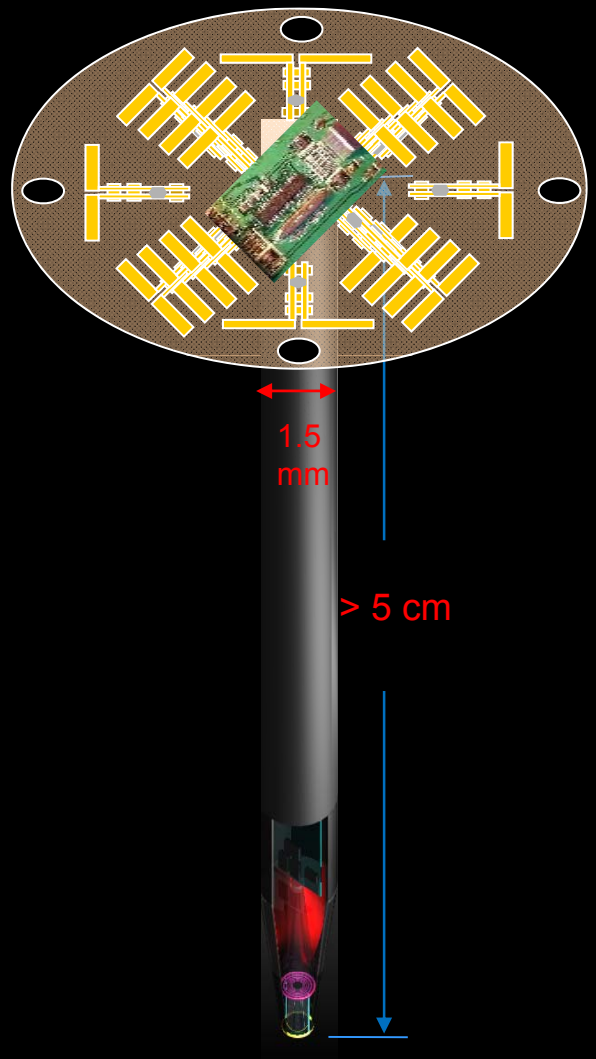


PPD Logic (internal) with TFRA or MIC



Features of Probe Pin Device

- Selection of Targeted Spectral Line for μ-SM:
  600 nm < λ < 1000 nm
- Spectral Resolution: ≤ 10 nm
- Downsize of Micro-Spectrometer:
  < 2 mm
- Platform Design for Other Sensors Integration:
  p, T, V, and chemicals
- Wireless Power Feeder and Integration:
  both MIC and MW
- Telemetry Circuit and Test with Skin Tissue:
  FM mode
- Chip-scale Design of Electronics:
  Miniaturization



Summary

- Neural Sensing Probe Pin Device with micro-spectrometer is under development.
  - Micro Spectrometer Component Test Platform was set up.
  - The world's smallest optical path volume ($1mm^3$ was achieved with 0.75mm diameter.)
  - This is $1/1000^{th}$ volume compared with today's smallest commercial spectrometers ($1cm^3$)
  - Demo model developed with actuator-controlled focal length as a stop-gap approach
  - All basic electronics for sensor, telemetry, and power coupling were fabricated, but required chip-scale miniaturization
- Prototype SOM characterization system is developed to measure intensity, phase, and polarization of passing lights through many new optical materials while applying various physical/chemical quantities on the materials.
  - A miniaturized compact system has USB interface and exchangeable components for various R&D and commercial applications.
  - SOM system and software are Tech-Transfer ready
- Wireless Power Transmission test using polyurethane layers and pig skin was satisfactorily performed.
  - MIC was proven to be effective for short range power transmission, like a hat system
  - TFRA was effective for short (near-field capacitive coupling) and long (far-field) range power transmission.